White Paper

Relevance and Cognition for Pervasive Computation at Scale

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A great deal of the challenges to be addressed to enable Pervasive Computation at Scale (PeCS) stem from the **strong human/social/behavioral dimension** associated with networked content and services, including frequently the mobility sub-dimension, and the **explosion of content/services/utterances/attributes** generated by users and the physical environment. The participatory generation of content is now a common phenomenon as network users are both producers and consumers; common examples include YouTube, Flickr and grassroots journalism. Creation and publication of such content is steadily moving to mobile devices, which are consequently producing information artifacts that are rich in meta-data. In addition, content generation is progressively being extended to fixed devices in the environment (see below) rendering these devices becoming "live". Among the multitude of heterogeneous fixed and mobile devices there is less clear-cut separation between who generates the content, where content is stored and who consumes the content. A consequence of increased participation is the infinite scale of content that may result. To make unprecedented amounts of content available and to unleash new classes of applications, a rather "revolutionary" approach to coping with the scalability issues needs to be developed. Within this the ability to **establish relevance** will be crucial, yielding scalable approaches to suppression of what is not relevant.

As humans are increasingly equipped with dedicated mobile computing and communication equipment, their networked interfacing would be implemented through the generation, processing and exchanging of attributes that would "automate" the process of defining, coping with and exploiting computer-interfaced social structures and interactions with the physical world. An infinite scale of such attributes should be envisioned unless measures are taken to contain them where/when useful (relevance).

There is an increasing trend of content being created directly in the physical environment. The development of "lightweight" wireless technology enables a much wider range of objects to participate by creating, storing and forwarding information and content to other devices in range. Ultimately this will lead to a physical world that is saturated with content, far beyond the current Internet. At the simplest level, the environment will be propagating data or information on a massive scale: stores and shops may be broadcasting content about sales, hotels may be wirelessly announcing the availability of rooms, a post box may be giving information about collection times and so on, leading to massive content embedded locally. This can be engaged implicitly (e.g., to determine context) and also explicitly (e.g., provide information directly to the user). Much content from the environment will be time limited (in terms of utility) and transient, and thus not be able to be indexed or obtained in any centralized form.

While the benefits of such content-driven pervasive computing environment at large scales are rather obvious, the challenge is to master the curse of scalability that manifests itself in numerous ways:

- The design should ensure that a load increase is more than compensated for by *a resultant increase in the available resources*, so as to establish scalability; the dual role of content consumer and network service provider by an entity in PeCS environment could support this through proper design.
- While the demand distribution of the most Content/Services/Utterances/Attributes (CSUAs) is close to 0, their *conditional spatio-temporal distribution* is away from zero; by employing spatially available resources for limited time one can create services of value, while mastering the curse of scalability.
- Autonomicity has been an instrument for decentralizing and distributing control and management complexity and it naturally emerges in PeCS. Autonomic principles and particularly interactions of autonomic elements should be mastered to bring scalability; *a science of autonomic interactions*.

- Would economic models of growth based on mass production and economy of scale be applicable to PeCS? Frequently in the past tiny *hidden costs* were considered negligible until the scale of usage caused such a cumulative increase in those costs that broke the original solution - perceived as scalable - apart. The scale of the emerging PeCS could quickly get us to the limits of an approach thought to be efficient for medium-large scales of practical concern but turn out to be asymptotically non-scalable; *asymptotic* scalability should be the property to look for in such truly large scale environment.
- In PeCS there is a wealth of enabling resources beyond the classical bit transmission resource, such as storage, mobility, processing, compression, energy, and other resources. It would be important to assess their potential role, understand their equivalences and *resource exchange "rates"*, and possibly identify a common denominator for assessing their monetary and environmental value. This could constitute another instrument for mastering scalability.
- Employing the concept of cognitive self-awareness at the device, at the artifact and at the system level could help master the scale. Human behaviour with respect to decision making (*human cognition processes*) could be utilized to manage CSUAs in a way that *matches human expectations* and bring scalability to an overwhelming environment. The cognitive ability of the brain to efficiently assert relevance (or irrelevance), extract knowledge and take appropriate decisions, when faced with partial information and disparate stimuli could be exploited to develop functional models of the core cognitive processes that allow humans to assert relevance and achieve knowledge from information through mechanisms such as inference, belief, similarity and trust.

Background: Besides the extensive background on network protocol design and stochastic modeling/evaluation, the following 3 major focuses over the last decade are very relevant.

<u>Innovative framework for scalability</u>. Highly referenced and fundamental theoretical work on scalability in early 2000's [1] has developed a framework for defining and computing scalability in ad hoc mobile networks. Application of this framework has led to the design of a protocol (HSLS) that has been implemented, adopted and deployed by community networks such as the Univ. of Illinois Community Network in the early 2000's [2], as well as adopted by several US Army radio prototypes.

<u>Autonomic Communication/Networking</u>: A major initiative in Europe on Situated and Autonomic Communication (SAC) was pursued by 4 EU-funded large research projects. By being involved in 3 out of the 4 (BIONETS, ANA, CASCADAS), [3], substantial experience on autonomic behaviors and designing for autonomicity has been obtained, in addition to a good overview of the related efforts in Europe. Autonomic behaviors and designs are key to achieving pervasive computing at scale.

<u>Social – Content networking</u>: In the context of the active EU project SOCIALNETS, [4], significant experience has been obtained regarding the interaction of human behaviors and content networking in areas such as: autonomic service/content migration exploiting social metrics; user similarity indices as drivers of behaviors in content networking and community detection / formation. Current focus is on ways to cope with user- and environment -generated content explosion in a scalable manner (just started EU project RECOGNITION, [4]), aiming at employing decision making techniques of the human brain in coping with content networking decision in the presence of limited or indecisive information. These projects are interdisciplinary and involve anthropologists, psychologists, and physicists.

References:

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